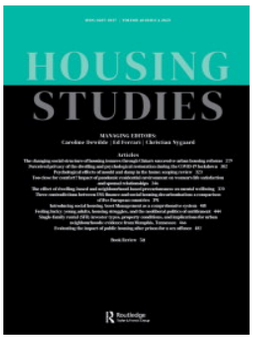

Housing Studies

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/chos20

Understanding residents' experiences of home, health, and wellbeing in new and novel low carbon homes

Kate O'Sullivan, Fiona Shirani, Nick Pidgeon & Karen Henwood

To cite this article: Kate O'Sullivan, Fiona Shirani, Nick Pidgeon & Karen Henwood (22 Jan 2025): Understanding residents' experiences of home, health, and wellbeing in new and novel low carbon homes, Housing Studies, DOI: 10.1080/02673037.2025.2453015

To link to this article: https://doi.org/10.1080/02673037.2025.2453015

Published online: 22 Jan 2025.

HOUSING STUDIES
https://doi.org/10.1080/02673037.2025.2453015

Routledge
Taylor & Francis Group

Understanding residents' experiences of home, health, and wellbeing in new and novel low carbon homes

Kate O'Sullivan[a], Fiona Shirani[a], Nick Pidgeon[b] and Karen Henwood[a]

[a]School of Social Sciences, Cardiff University, Cardiff, UK; [b]School of Psychology, Cardiff University, Cardiff, UK

ABSTRACT

As significant contributors to CO_2, UK homes must be decarbonized. Active Homes represent a possible route to addressing both societal concerns and policy ambitions, while providing comfortable high quality living environments. However, changes to the material structure of homes have potential implications for people's ability to live well within them. Our qualitative longitudinal (QL) research as part of the living well in low carbon homes project unpacks how changes brought about by living within an Active Home are experienced by residents, including to self-reported health and wellbeing. We explore how living in an Active Home may challenge expectations of home, including embodied experiences of comfort and intrinsic values of privacy and control. We suggest that it is important to recognize that these different but interwoven elements impact upon residents' sense of home, and health and wellbeing, which has implications for future innovative low carbon homes.

ARTICLE HISTORY
Received 28 April 2023
Accepted 23 December 2024

KEYWORDS
Health and wellbeing; low carbon; home; values; neighbourhood design; smart home

Introduction

The UK Government target of net zero carbon emissions by 2050 requires decarbonization across all sectors (CCC, 2022). As nearly 80% of the carbon dioxide emitted from buildings in the UK is from residential buildings, the decarbonization of homes is essential (CCC, 2022). Alongside decarbonization, changes to homes may offer opportunities to address other pressing social issues, such as improvements to health, representing potential co-benefits (Willand *et al.*, 2019). Health has been defined as a 'state of complete physical, mental, and social wellbeing and not merely the absence of disease or infirmity' (WHO, 1995). However, this definition has been critiqued as unobtainable, with more recent conceptualizations of health as a complex adaptive system and dynamic state (Lovell, 2018). Associated with health is the

CONTACT Kate O'Sullivan osullivankm1@cardiff.ac.uk School of Social Sciences, Cardiff University, Cardiff, UK

concept of wellbeing, understood as the state of being comfortable, healthy or happy, including life satisfaction (Creaney *et al.*, 2021). Relatedly, 'quality of life' is a term which is used to describe the influence of all aspects of an individual's life, which can include their health, on how they feel (Lovell, 2018:5). These interrelated concepts have been drawn on in existing research concerning buildings, with residential satisfaction recognized as one aspect affecting quality of life (Wang & Wang, 2016). Thus to understand how transformation of homes through decarbonization impacts upon residents' ability to live well, consideration should be given to how residents perceive their quality of life, which might encompass, but not be restricted to physical, mental, and social health and wellbeing at different points in time.

Connections are well established between indoor environments and building occupants' health and wellbeing (Rolf *et al.*, 2020). Research has highlighted how architecture influences mood, habits, and attitudes, as well as how different aspects, such as lighting and ventilation, contribute to resident experiences of comfort and satisfaction (Wågø *et al.*, 2016; Ellsworth-Krebbs *et al.*, 2019). Conversely, poor construction or maintenance of building structures (Gibson *et al.*, 2011; WHO, 2018), indoor air quality (Lowther *et al.*, 2019), lighting and acoustics, can all contribute to 'sick' (Murphy, 2006:2), 'diseaseogenic' buildings (Rice, 2019:156). Cold indoor temperatures and poor indoor air quality are linked to higher levels of asthma, increased blood pressure, respiratory conditions and spread of communicable illnesses and disease, as well as poor mental health (WHO, 2018; Rice, 2019; Sharpe *et al.*, 2022; Willand *et al.*, 2015). Recent crises, such as the Covid-19 pandemic, have increased attention on the healthiness of indoor environments. Therefore, innovations to the home that alter the indoor environment are an important focus of research attention.

While the connection between material environments and resident health and wellbeing is important, attention must also be paid to 'less tangible' (Rolf *et al.*, 2020:2) elements of home. Recognizing house as home means considering material infrastructures and technologies as well as the values, meaning and expectations associated with home (Després, 1991; Rolf *et al.*, 2020). Attention has been drawn to the way in which terms such as housing, household, home, house, domestic and dwelling appear to be used interchangeably, yet meanings of and distinctions between these concepts warrant greater attention in energy scholarship (Ellsworth-Krebbs *et al.*, 2015). Whilst building or house may refer to the physical structure, notions of home are linked to important social aspects such as comfort, identity, security, and privacy (Ellsworth-Krebs *et al.*, 2015), as well as routines and perceived non-negotiable psychosocial norms associated with home-life (Gibson *et al.*, 2011; Shirani *et al.*, 2020). These interrelated aspects may contribute to feeling 'at home', an important aspect of wellbeing (Wågø *et al.*, 2016). A sense of home or 'at-homeness' (Seamon, 1979:70) involves the integration of the body (daily routines), self (identity and values), and the material environment. For example, Öhlén *et al.* (2014) indicate how feeling at-home and health and wellbeing are both states of being and experiential processes involving encounters between the body, self and material environment, with general meanings of being safe, connected and centred are related to at-homeness. Housing design that impact processes of connection between body, self, and environment may also disrupt the sensed experience of at-homeness and

health and wellbeing (Öhlén *et al.*, 2014; Wågø *et al.*, 2016). Thus, in exploring experiences of health and wellbeing at home, it is important to consider the material environment and how home is expected to be lived in and valued, as well as how these interplay through the lived and embodied experience of households. In this article, we explore resident experiences of moving to new build Active Homes, designed to be energy efficient, capable of producing and storing energy, focusing on the impact of these homes regarding health and wellbeing. In order to situate our work within the research landscape, we first consider existing work on innovative home developments.

Innovative home developments

There is a need to develop housing solutions that can address multiple societal concerns for climate change, economic and energy crises, and population health and wellbeing. Several innovative sustainable building conceptualizations and certification schemes aim to address these different issues (O'Sullivan *et al.*, 2020). For example, biophilic buildings aim to enhance the health and wellbeing of occupants by increasing nature in urban and built environments leading to more frequent human–nature interaction (Xue *et al.*, 2019). Access to nature and green spaces has long been recognised as holding health and wellbeing benefits, fostering a sense of community and place, facilitating neighbourly familiarity, and affecting feelings of security and safety (Mel & Whitten, 2021; Xue *et al.*, 2019). Attention is increasingly paid to incorporating green spaces in new housing developments (Gibson *et al.*, 2011; Wågø *et al.*, 2016; Wang & Wang, 2016) to enable a sense of community and place, wellbeing and quality of life. A different home concept, smart homes, incorporate information technology to enable efficient use of resources within a home, and between a home and wider infrastructural systems. Smart homes are positioned as a means of addressing climate change while also providing energy efficient, comfortable, and healthy homes (Fabi *et al.*, 2017). Smart homes may hold health and wellbeing benefits, for example, through supporting independent living or streamlining daily activities and services. However, smart home control and operation alters residents' autonomy and control over their private space (Creaney *et al.*, 2021; Hansen & Hauge, 2017). These changes can affect feelings of control and privacy (Despres, 1991), and lead to concerns around access to personal data security and privacy (Fabi *et al.*, 2017), holding potentially adverse wellbeing outcomes (Hansen & Hague, 2017). Fell (2021) has considered tensions between occupant expectations and the commercial interests of heat system operators in externally controlled heating systems, noting how locating some control with residents in the form of override options, appears to be important in contributing to resident satisfaction with such systems.

Finally, other building concepts place emphasis on building energy demand and associated CO_2 emissions, and how this can be reduced. For example, Passivhaus building design, emphasises 'in-situ' energy efficiency properties such as thermal insulation and natural ventilation to reduce energy demand required for residents to achieve thermal comfort (Wågø *et al.*, 2016). Net-zero buildings (NZEBs), whether focused on net zero CO_2 emissions or energy consumption, incorporate renewable energy production with building structure efficiency to

offset energy consumed and/or CO_2 emitted during the buildings life span (D'Agostino & Mazzarella 2019). Technically, Active Homes hold similarities to that of Passivhaus and NZEBs, for example, incorporating energy efficient building structure and integration of renewable energy production. However, Active Homes also integrate energy storage and vehicle charging technology. Together with incorporation of smart energy technologies, Active Homes can trade energy with other Active Buildings, or system-scale energy networks, providing energy system flexibility. The realization of Active Homes involves new configurations of building design and materials, energy technologies, digital energy systems and controls that are often different to past experiences of housing and energy, which might affect resident health and wellbeing.

New low carbon or retrofitted homes often involve different heating systems and research has explored how residents experience these in relation to their competencies with existing heating technologies (Madsen *et al.*, 2023). Heating is particularly relevant to discussions of homes and health as energy efficiency interventions can lead to improved warmth, with benefits for both physical and mental health, although fuel costs remain an important consideration (Willand *et al.*, 2015). Studies have indicated that residents may struggle to achieve thermal comfort as they adjust to heating systems that operate over longer periods, at lower temperatures, or without material elements, such as radiators, that residents were used to Madsen (2018). Madsen (2018) has also critiqued the focus on specific quantifications of thermal comfort achieved through energy-efficient technologies that presuppose rational behaviour by residents. These critiques suggest that such measurable aspects do not adequately reflect what makes residents feel comfortable as this lacks holistic understanding of residential wellbeing (Wågø *et al.*, 2016). Previous work has illustrated the significance of heating in accounts of caring for vulnerable family members as a non-negotiable aspect of energy use (Shirani *et al.*, 2020), or how window opening can be important in achieving ventilation of indoor spaces associated with a healthy home, as well as enabling connections to nature and care for children (Wågø *et al.*, 2016). Ellsworth-Krebs *et al.* (2019) found that participants in their study of home comfort used relaxation as a synonym for comfort, highlighting that there is more to being comfortable at home than temperature. Instead, they describe comfort as 'the state of relaxation and wellbeing that results from companionship and control to manage the home as desired' (pg. 202). Similarly, Wågø *et al.* (2016) suggest that wellbeing in the home is dependent on a variety of elements, including usability, possibilities for resident control, and the degree to which residents' expectations for their homes are fulfilled.

Alongside new heating systems, active home developments include energy production technologies, such as solar panels, enabling households to both produce and consume their own energy (Stikvoort *et al.*, 2020), changing the role of households in the energy system from consumers to 'prosumers' (Ellsworth-Krebs & Reid, 2016). Some also include ground source heat pumps, arguably a form of heat prosumption (Ellsworth-Krebs & Reid, 2016). Studies of microgeneration (small-scale electricity or heat production, for example from residential solar panels or ground source heat pumps) have shown residents changing their behaviour to consume as

much as possible of their own electricity (Palm *et al*., 2018). This may go beyond financial motivations to reduce cost or overall consumption, recognising instead how prosumption may give a different use value to energy; for example, residents' sense of satisfaction from using energy produced by their own home's resources (Ellsworth-Krebs & Reid, 2016). Existing research has indicated differences in householder engagement with solar panels, with those who have opted to install solar panels on existing homes more engaged than those moving into new homes where PV was included (Winther *et al*., 2018). Such differences indicate the need to consider the particular experiences of those moving into newly built homes with a range of technologies included.

Active Homes are an innovative conceptualization of low carbon housing that alter the materiality of home. This may also have implications for how homes are valued, understood, and lived in, which in turn can hold intended and unintended outcomes for residents' health and wellbeing. While such changes can 'be highly positive for health,' they may also 'generate new and unforeseen health risks' (WHO, 2011:3, see also, Rolf *et al*., 2020; Sharpe *et al*., 2022; Willand *et al*., 2019). Thus, despite the ambition for Active Homes to hold multiple benefits, including for health and wellbeing (O'Sullivan *et al*., 2022), such outcomes are not guaranteed. The interplay between material housing conditions, a sense of home and resident health and wellbeing has been explored and measured in a range of ways including through self-reported surveys (Wang & Wang, 2016; Willand *et al*., 2019), combinations of self-reported surveys and post-occupancy interviews (Rolf *et al*., 2020) or household qualitative open-ended interviews (Ellsworth-Krebbs *et al*., 2019). A number of studies have indicated the importance of a qualitative approach to understanding the experiences of occupants. For example, in the process of low carbon retrofit (Chiu *et al*. 2014), with energy neutral homes and technologies (van der Grijp *et al*., 2019), and to elucidate a perspective from before, during and later stages of living with new heating systems (Madsen *et al*., 2023). These studies also note the 'dearth' of such insights (Chiu *et al.,* 2014) in existing research. Drawing on findings from qualitative longitudinal (QL) research with Active Home residents in South Wales, UK, this paper addresses an identified need for studies that consider the experiences of low carbon home residents (Berry *et al*., 2014). We take an overarching view of the interrelated changes brought about by moving to an Active Home and how these are negotiated by residents (Berry *et al*., 2014) with a particular focus on self-reported health and wellbeing.

Methods and materials

The data presented in this article were collected as part of the Living Well in Low Carbon Homes (LWLCH) research project, which explored the lived experience of active homes, developed in Wales, UK between 2019 and 2022. LWLCH was part of the Active Building Centre Research Programme, which aimed to demonstrate how the UK construction and energy sectors may decarbonize through the deployment of Active Buildings. The realization of Active Homes involves potential transformations of energy and building infrastructures, the roles and responsibilities of energy companies and residents, the emergence of new energy agents, as well as

Table 1. Case sites.

Case site No.	Development size and tenure	Key characteristics and relationship to health and wellbeing	No. participants
1	>150 homes (2 bed flats to 4 bed houses) Owner-occupied with some shared ownership.	• Aim to provide resident thermal comfort and low energy costs *via* energy management service (direct load control) managing resident energy production, demand and storage • Energy and hot water resident management App • Customer experience team and helpline pre- and post-occupation • Neighbourhood community green space	17
2	<20 homes (1 bed flats to 4 bed houses) Social rent and owner-occupied.	• Aim to provide resident thermal comfort and low energy costs *via* combination of energy efficient built design, thermal gains, and energy production and storage • Modular wood construction, materials from local supply chain • Non-Volatile Organic Compound (VOC) paints • Air quality sensors to alert residents when un/healthy levels of indoor air pollutants, or humidity reached • Planned community allotment	11
3	<20 homes (1 bed flats to 3 bed houses) Social rent.	• Aim to provide resident thermal comfort and low energy costs *via* combination of energy efficient built design, retention and recycling of thermal waste (MVHR and transpired solar collectors), and energy production and storage • Transpired solar collector • Solar PV film roofs • Mechanical Ventilation with Heat Recovery (MVHR) to improve air quality • Community green space and preservation of existing mature trees	9

changing energy policy and regulations. Such changes mean that in the UK, real-life examples of Active Homes are currently limited to small-scale demonstrator developments (O'Sullivan *et al.*, 2020). There are a number of Active Home developments completed or underway in Wales, partly down to financial support *via* the Welsh Government's Innovative Housing Programme (Welsh Government, 2020), which makes case sites in Wales relevant for research attention. In this article, we focus on three case sites, outlined in Table 1. The sites vary in their locations, stakeholder composition, and primary ambitions, in addition to the material design, configurations of energy technologies, digital capacity and governance, and resident tenure (O'Sullivan *et al.*, 2022). Common to all our case site developments is the inclusion of solar energy production, battery storage, high levels of insulation, and electric heating.

The project design included stakeholder and expert interviews, exploring their performance ambitions for the homes and how they imagine future residents may live within the homes, which have been discussed in our previous publications (Shirani *et al.*, 2022a,b,c). This article focuses on QL resident interviews, carried out with Active Home residents once within the month prior to moving into their new Active Home, and then twice within the first year, at approximately 3 and 12 months post-occupancy, to provide a detailed and dynamic picture of Active Home living. Interviewing participants over the course of a year enabled us to cover experiences over different seasons, weather conditions and related energy generation and demand changes, which had implications for thermal comfort and perceptions of light and airiness.

Information about the research was distributed to all future residents of our case sites, either by housing officers or sales teams. Individuals were invited to

contact the research team if they were interested in taking part and 37 residents participated. Due to the Covid-19 pandemic, most interviews were conducted remotely by members of the research team using video conferencing software or telephone, with some later interviews conducted in-person. All interviews were audio recorded and transcribed verbatim, then transcripts were coded thematically using NVivo software. We adopted an iterative coding process, using both a priori and inductive codes. Coding was carried out by multiple research team members, with regular discussions to ensure coding compatibility. In this article, we include discussion of data coded thematically under 'health and wellbeing'. Questions relating to health and wellbeing were included in each interview phase, in order to elucidate any change over time, thus data included specific responses to these questions. In final interviews, participants were also asked directly about quality of life. Given the identified connections between wellbeing and notions of control, security, comfort and privacy, data coded under these themes are also explored. We present extracts from different waves of interviews where relevant discussions emerged, alongside extracts from the same participants at different time points, showing how aspects of health and wellbeing were discussed across their first year of Active Home residence. Participants have been assigned pseudonyms to maintain anonymity, which we use for data extracts below, alongside the case site number they resided in. Given coherence between expectations and experience is important for residents' wellbeing (Wågø *et al.*, 2016), we begin by considering pre-occupancy expectations, before presenting post-occupancy experiences in relation to a range of themes.

Results

Expectations of a healthy home

Participants described a range of motivations for moving to an Active Home development, which varied according to their individual circumstances (Shirani *et al.*, 2022c). The Active features of the home were an important part of many people's decision to move, aligning with individuals' views on sustainability and addressing climate change concerns. However, for some, it was simply a case of finding a house in the right location and budget. The majority of participants expressed expectations that high levels of insulation and energy generation technologies would result in reduced energy bills. For some participants, the decision to move to an Active Home was explicitly discussed in relation to expected improvements in health and wellbeing. A small number of participants had, or lived with household members who had, ongoing health conditions or limited mobility, with conditions expected to worsen over time. For these participants, a newly built modern home was expected to make life easier in the present through offering contemporary standards of accessibility and comfort, whilst the Active features also contributed to expectations that the homes would be 'a place that's future proofed as well to a certain extent' (Ian, 2). Other participants who had experienced, or lived with household members who had, respiratory issues, expected that 'moving into clean air' (Leah, 3) would lead to health improvements. As Janet

explains, living in an old hard to heat property had led to health issues, which she expected to improve on moving to an Active Home:

> Well, when they come, she said, "No wonder your breathing's bad," she said, "Why haven't you got the heating in there?" She said, "It's so damp and cold in this place." Do you know what, I had the heating on last night, right, and I still sat here and I shivered … I think it's going to be a lot better and I'm sure it's going to help me health-wise as well. (Janet, 2)

The move to an Active Home was expected to provide affordable thermal comfort, which, as Amy indicates in her pre-occupancy interview, was also expected to improve mental health and wellbeing:

> I mean, both of us have been really suffering over the winters being here, and it's just not pleasant being freezing cold at night, and waking up freezing cold … So we are just really hoping that we can have a warm house. That's one of the main reasons that we're excited about it, because it really does get you down … You know, you lose all motivation to move, because it's too bloody cold to do anything …. So, yeah, I'll definitely be more active because I'll actually be able to go out in the garden and stuff. I'm very excited about that. (Amy, 2)

Prior to moving, several participants did not have access to gardens and, the move to an Active Home with private garden space was something that they felt would lead to improvements in everyday life.

> I do believe it's going to bring me benefits of feeling secure so I can deeply relax and feel warm and safe and cosy … and to have my own garden is going to be amazing … I think it's going to bring me tremendous benefits of relaxation and I think, therefore, my creativity, my health, everything will really just be able to flow from there. (Julie, 2)

These pre-occupancy responses highlight a range of expected health and wellbeing benefits that participants across the sample expected from a move to an Active Home. Including interrelated issues of improved accessibility, air quality, affordable warmth, and improved physical and mental health through secure accommodation and access to green spaces. In the remainder of the article, we focus on post-occupancy experiences, exploring whether coherence between expectations and residential experience, important for wellbeing, were achieved.

Layout, light, and air

Post-occupancy, participants were overwhelmingly positive about the layout and finish of their homes, this was commented on regardless of the season in which their interviews took place. For participants with mobility issues, or who were carers for other household members, the accessible layout and convenience of their new home was felt to contribute to significant improvements in their everyday lives. One participant described his life as '500% better' and another as 'the best thing we've done'. For some participants who themselves, or family members, were reliant on wheelchairs or mobility scooters, they spoke of increased privacy, autonomy, and freedom that resulted from the move.

Across all case sites, a number of participants expressed positivity about how spacious and well thought-out their homes were. Several participants described internal spaces as 'light' and 'airy', which had a positive impact on their 'mood' as Amy describes below. Revisiting Amy during the summer, a few months post-occupancy, she indicated that there are multiple elements of her Active Home that have had a positive impact on her everyday life. This illustrates how some participants found it difficult to disentangle the experiences of these non-active aspects of their new home from the active aspects such as 'heat':

> There's a lot of things I like about it, I don't know if I can pick one thing in particular, but I like how, how light it is in here. Because, and obviously the heat, but again, I've always lived in really dark, dingy houses. So to actually have a bright house, that, it, it makes a huge difference to your mood. (Amy, 2)

After living in cold rented properties for some time, and having spent a winter in her new home, Amy described having a warm home as a "big relief". Aside from benefits to comfort and energy savings, Amy spoke of other 'therapeutic' benefits:

> It makes a big difference, you know, not, sort of, spending my days tryna, keep warm, or, like I said, I really like growing plants. I've got a lot of houseplants, and I've never really been able to successfully do that in the other house. And, you know, a lot of people will agree that like growing things, and having plants in the house, it's quite therapeutic. And to, so to be able to do something like that, that I enjoy doing is, is really nice as well. (Amy, 2)

Amy had found the home to be efficient, meaning she was no longer so conscious of her energy use and switching off appliances as she had been in her previous house due to concerns about cost. She described how this aspect in particular 'made a huge difference to my, just general sort of state of mind'.

Post-occupancy, most participants were positive about air quality in their Active Home, describing perceived health improvements. These were particularly noticeable for participants like Rose, who had moved from older properties:

> I think the air quality feels nice here. The other thing I have noticed actually is that I had real kind of nasal problems in the old house, and that feels like it's completely cleared up in this house. And I think it was probably to do with mould, or damp, or something in the old house that's just not an issue here. (Rose, 2)

Air quality was a particular point of discussion at case site 3, which had mechanical ventilation with heat recovery (MVHR). Some described how having filtered air was reassuring, giving "peace of mind" or leading to perceived health improvements in respiratory conditions:

> Since I've lived here, I haven't had a cold. So it must be something to do with the clean air, that's the only thing I can put it down with. And my mum suffers with COPD. And when she's really ill, she comes here because she knows that she's going to get better within 24 hours, that's what she says, I've got a magic home. (Shannon, 3)

However, others described the MVHR as unnecessary, preferring instead to open windows for ventilation. As residents were unable to completely shut off the MVHR system, some described challenges with the cold air emitted perceived to be working against the heating system, leading to greater energy use and cost:

> So you're spending all that money on the electricity to try and warm the house up. But yeah, you've got that cold air blowing into the ceiling. (Kevin, 3)

For participants like Kevin, where the home's technologies did not appear to be aligned with one another this led to challenges in achieving thermal comfort, with concerns about cost and control, which we consider below.

Comfort, cost and control

Across the case sites, the energy technology configurations and high insulation envelopes of the homes mean that heating systems work at lower temperature settings and over longer time periods than more conventional gas or oil central heating. Many participants spoke of challenges acclimatizing to this, experiencing periods of discomfort as they established a new heating routine. For some, being unsure of how and when to operate their heating system affected their perceptions of control and autonomy, with several describing frustration with the new systems. In struggling to achieve comfortable temperatures, some participants then experienced concerns related to their energy use and cost. To regain control over their thermal comfort, some spoke of using free-standing plug-in heaters, or self-rationing and layering:

> So what happens is, is that we just put on the dressing gown, the socks, the big furry slippers, the throws over the settee. That's what we do. It's not the way I want to live … we shouldn't have to live like this in an eco-home. (Helen, 3)

However, some participants described how additional layering was not a feasible approach for their household, often because of caring for young children or household members with pre-existing health concerns, where achieving comfortable room temperatures was important for practices of care (Shirani *et al.*, 2022b). In these cases, higher than anticipated bills were expressed as being outside of their control, and adversely impacting mental health (Willand *et al.*, 2015).

Whilst thermal comfort remained a concern for a minority of participants, most described the houses as warm and expressed a sense that they were well-insulated and retained heat well. For some like Emma in her initial post-occupancy interview, even though she had not yet experienced a winter in the home, prior feelings of anxiety and dread as winter approached were alleviated:

> I'm not worried about winter. Which I think every year previously, it was, sort of, a bit of a dread going into winter cos you knew it was gonna be really cold. And it's always that, sort of, battle of trying to manage how cold you wanna be versus how much you wanna spend on your energy bills. (Emma, 2)

Further interviews with participants like Emma after experiencing a winter in their homes revealed that in most cases homes had been warm, meeting pre-occupancy

expectations. However, this was not a universal experience and some had ongoing issues with achieving thermal comfort.

Those participants who were experiencing lower bills since moving to their Active Home described this as particularly fortuitous in light of the energy crisis and significant price increases, which occurred during the course of our research. When we revisited Emma for her second post-occupancy interview, low bills featured prominently in her discussion of aspects of the house that made her feel happy:

> I think being in, in a nice house, kind of, just makes you feel happy, and all the bills and things are a lot less than what I was paying previously. So obviously, you know, financial stress and things like that haven't been, haven't been bad at all. [later] No, it's really good, especially at the moment with the energy prices going up so high, to know that you're not having to, sort of, choose between whether you wanna put the heating on or, you know, other things. (Emma, 2)

Residents' understanding of how the different technologies in their energy system worked together and how they should be managed day to day, varied between households and case sites. Across the case sites, several participants spoke of wanting to gain a holistic understanding of how their homes worked in order to manage their energy autonomously. Without this information, some described how the ability to adjust their daily routines to maximize financial and carbon benefits were limited:

> You really have no insight into the workings of the house, you have no idea what's going on here. We have absolutely no idea how much energy we're using. There's no way of telling. Until you get the bill. And that's a bit too late. (Christian, 1)

All case sites have ongoing technical data monitoring of at least some of the homes' performance outputs. At case site 1 this is carried out by the energy service provider as a part of their energy management operations, and by third party organizations at case site 2 and 3. At case site 2, some participants spoke of being unaware of and 'uncomfortable' (Louise, 2) with the technical monitoring, which also involved remote access to the energy display monitors in their home. Unexpected remote access to the private space of participants' homes without household consent could affect feelings of control and privacy. Others across the case sites felt that the disparity in control between residents and housing developers or energy service providers was problematic:

> The house kind of just runs itself now. But there's like a lot of stuff that you can't change on here, but [the energy service] can their end. And the same if anything goes wrong, they can do so much their end that we can't do, and I hate that, yeah, just hate it. I hate relinquishing control, and they have the control, and I don't like it. (Natalie, 1)

Here, Natalie's description of how the house 'just runs itself' relates to the ambitions some developers described in relation to external control of the Active Home as preferable because it removed the burden of managing their energy system from residents (Shirani *et al.*, 2022a). However, several participants found this lack of control problematic, indicating a discrepancy with the developers' aims (see also

Fell, 2021). Whilst some participants expressed concern about the 'big brother' aspect of their Active Home set-up, others were more sanguine:

> It is a big brother installation, there's no doubt about it, the people at [energy service] can see exactly when we take a shower, when we cook, what temperature we set our house to, and when we turn the lights on and off, and they can check absolutely everything … it hasn't bothered me all that much, probably because I trust that company here. It's not like Facebook that sells everything to the highest bidder. But it is a concern. Yeah. I don't see any way around it. What would you do? I mean, once you have an electronic control on your, on your house, I mean, somebody can see the data. (Christian, 1)

Participant responses also highlight how important relationships between residents and housing developers or energy service providers are. At case site 2 residents described being uninformed about data monitoring or remote access, while at case site 1, more information and continued customer support (due to the energy management service) meant residents like Christian were aware of monitoring arrangements. As per Rolf *et al.* (2020:14), establishing positive relationships between residents and those who are responsible for delivering 'housing service satisfaction' can 'underpin [households'] sense of control, autonomy and safety, with positive impacts on their wellbeing'". Therefore, while data monitoring was perceived by some as an infringement of their control and privacy, explanation of the purpose of such monitoring, and experiences of other beneficial outcomes (such as fault fixing) meant the majority of participants expressed neutrality or positivity about the monitoring arrangements, although some suggested that they would like feedback from this process. Across the case sites, the mix of technologies comprising the energy systems, along with data monitoring, require a significant level of electrical wiring and Wi-Fi capacity, which raised health concerns for several participants, as we consider below.

Technology and emissions

For some participants, technologies in the home raised concerns for both immediate and longer-term health and wellbeing impacts. In her pre-occupancy interview (see pg7), Julie envisaged her Active Home leading to health and wellbeing benefits. However, post-occupancy she expressed concern about the potential impact of the technologies in her home:

> So for me, this is not an eco-home in terms of human health, it's an eco-home in terms of passive solar power, brilliant. It's lovely that the, you've got all this light, that you've got all this insulation, that it's, it's built with local timber and non-toxic paints and, and adhesives. So that's all wonderful, but if you're creating an environment like that, that's full of harmful technology, then it's not, it's not eco in terms of the human beings living in here. (Julie, 2)

Others like Andrea spoke of perceived risks that could result from the installation of novel technologies in a domestic setting:

> I did ask the question whether, is that safe? Does it give off any kind of like not radiation, but you know what I mean … Because you're living in that, you know? Because they say people that live under electricity pylons, I don't know how true it

> is, but there's a bigger incidences of cancer etcetera, you know? So by storing energy in a house, are you actually putting people's health at risk? (Andrea, 1)

However, these perceptions were not universal, with some participants feeling that the homes were too low-tech and did not offer the level of control they had anticipated. Others indicated that the level of technology was appropriate and were satisfied with how the different technologies could work together, to reduce cost and carbon. Indeed, some participants described how their Active Home was helping them to live in a low carbon way, reducing feelings of 'pressure' and 'stress' involved with achieving lifestyles that aligned with their own personal and social identity (Wågø *et al.*, 2016):

> Because I know the house does most of it for me, it's kind of relaxing, really, to know that and not have to stress about it because the battery and everything and getting renewable energy and stuff like that. (Josh, 1)

In some of the homes in our study, residents had little choice over the materials used (such as flooring and paint). Aligning with established literature around indoor air quality and banal pollutants (Murphy, 2006; Rice, 2019), there was concern amongst a small number of participants that developer choices to include materials perceived to leach chemicals would adversely affect their health and wellbeing:

> We have underfloor heating, they didn't let us choose the flooring, and they put vinyl. And I understand it's plastic, when it's heated, it releases chemicals. I know there is a basic temperature limit. But I mean, I don't think that was a good choice, in an environmentally friendly house. And I really don't trust what kind of paint. I mean, it's a budget house, and I understand eco paint is expensive, but they could have asked us to pay more to, you know, there are things, little things that make, made me nervous. It remains to be seen if that's going to be healthy or not. (Francesca, 1)

Post-occupancy, some participants spoke of 'ripping out' flooring due to concerns about health and environmental impacts. This led to comments about the wastefulness of having to change something brand new, which was also perceived to contradict the ethos of sustainable living that they associated with an 'eco home' (Shirani *et al.*, 2022b).

Beyond the home

Outside the homes, both communal and private green spaces were viewed as important by participants. Cul-de-sac or crescent shaped neighbourhood layouts were valued for enabling a sense of security, or to communicate more easily in passing with neighbours. In line with architectural studies of cul-de-sac street design (e.g. Cozens & Hillier, 2008), participants suggested this layout facilitated neighbourly familiarity and affected their sense of security and safety:

> You do feel like because of the crescent your house feels like in a bubble. It feels… quite close to everybody else. So, it feels nice that if anything happened, like if you ever had a burglar, you feel like because of the way it's designed, somebody would see it, and somebody would be able to like support you or whatever. (Ben, 1)

Whilst the overlooked nature of public spaces in these designs were seen by some as enhancing security, it also inhibited use of the public spaces for leisure or recreational activities. The design of cul-de-sacs raises questions about walkability and accessibility (Cozens & Hillier, 2008), yet our participants did not raise this as an issue, instead highlighting how the broader site location was more relevant to transport decisions and to discussions of health and wellbeing. For example, participants at site 3, able to access to a range of amenities, such as shops, employment, or other transport links, discussed their location positively. For some, the location had resulted in significant changes and perceived improvements in mental and physical health:

> It's made such a difference to our, our lives, completely.… Being central in town means that we got access to far more than we had before, so now we can actually go out, we don't need to use the car so much. Now it's healthier, you know, now that we are out of a place which was full of damp, and this one is so much clearer, cleaner. [later] We're actually, less depressed, I think, you know, to be honest, that feeling of being stuck and isolated, has, is totally lifted because there's just more accessibility to things. (Leah, 3)

Enabling 'visual and sensory' connections to nature in new housing developments is broadly recognized as an important element of 'housing quality' (Wågø *et al.*, 2016:327) and something designed-in to all our case sites. However, in all instances, public green spaces were the last areas to be completed, were scaled back or did not resemble what had been envisaged. Several participants expressed disappointment about this, especially at case site 2 where the inclusion of such space had resonated with expectations of a garden village neighbourhood presented by the developer. As with the interiors discussed above, for some, the outside spaces did not reflect the sustainable ethos of the homes. For example, returning to Amy, who had initially been enthused at the prospect of personal and communal outdoor space, post-occupancy she expressed disappointment with how this had been realized:

> Even though this is considered a garden village, the, the whole point of this was that it's a shared community garden space, and also individual gardens. None of us have got outside taps. So, we're all really struggling to keep the gardens going. And that's one of the things I mentioned that we're all a bit disappointed by. (Amy, 2)

Others spoke of how outdoor spaces and the connections to nature they enabled were valued for affective outcomes on mood and sense of wellbeing, experiencing 'calmness' and feeling 'peaceful':

> It is just peaceful. With the area. And you know life now is just sitting in my garden now and there's a little squirrel running across the fence. [Laughter]. You know it's great, and the house itself is, it's just so lovely. There's such a good feel about it. (Lisa, 3)

These experiences highlight the importance of looking beyond the home itself to include broader considerations of community and location in reflecting on implications for health and wellbeing.

The whole package

Thus far, we have highlighted a number of different features that participants described making a difference to their health and wellbeing. Whilst some, such as layout and location, are not specific to Active Homes, others, such as filtered air through MVHR systems, thermal efficiency and reduced energy costs through prosumption, relate directly. Our research suggests that the interrelationships between these various elements are important to understanding resident experience of life in an Active Home. When asked what they liked best about living in an Active Home, many struggled to identify one element, instead emphasizing the importance of the 'whole package' (Pippa, 2) or the 'combination of things' (Ian, 2), including home design, technology, community and location:

> I think it's a whole ensemble of things really. So, if you were going to do it as a pie chart, then you've got the community, there's, it's all sort of interlinked together. They've all got, their own bigger part, they all meld into each other in the little rings in the centre. So it's a whole thing, the community, the economical, green aspect of it, the fact that our lives are extensionally better for living here. (Neil, 3)

Whilst in many cases this combination was seen to be working successfully, contradictions between different elements caused challenges. For example, when the MVHR system at case site 3 was perceived to be working against the heating, or when materials used at case sites 1 and 2 were felt to contradict the ethos of a sustainable 'eco home'. Whilst individual technologies such as solar PV and heat pumps might be established, it is the bringing together of a number of elements in an Active Home that is novel and perceived to support residents values, which is relevant for further research into potential impacts for residents:

> I don't have to worry about it as much … But it's like especially with the electric car, like the heating, the solar panels, the house, because it's more efficient, even if sometimes some of the other bits slip a little bit, I'm still doing something … So yeah, I think it's a lot, like it's nice because it takes the pressure off. (Sophie, 1)

Many participants perceived Active Homes as an inevitable direction for future housing and expressed pride at being 'pioneering' or 'trailblazing' in being some of the first UK residents of these homes. However, some emphasized the need for better understanding of how Active Homes operate and are experienced because 'people's lives really can majorly be affected' (Helen, 3).

Discussion

Our research findings highlight how residents described Active Homes as impacting health and wellbeing in a number of different, but interconnected ways. Several material elements of the homes, including the quality of the build, absence of damp and mould, and accessibility held impacts for perceptions of health and wellbeing. Beyond the homes themselves, neighbourhood designs were important, contributing to sense of community, belonging and safety, with green spaces also valued for their 'therapeutic' qualities, uplifting residents' mood (Wågø *et al.*, 2016), in addition to achieving several values associated with home, such as autonomy, privacy, security,

safe-haven and relationships (Öhlén *et al.*, 2014). Arguably such features may be considered expectations of modern new-build homes and not just Active Homes. However, in line with established literature, these features are recognized as influencing resident experiences of home (Wågø *et al.*, 2016; Ellsworth-Krebbs *et al.*, 2019) and health and wellbeing (WHO, 2018; Lowther *et al.*, 2019; Rice, 2019; Sharpe *et al.*, 2022; Willand *et al.*, 2015) and can be improved or compromised through the installation of interventions to address climate change (WHO, 2011). As our research demonstrates, participants described how the home is experienced holistically in relation to health and wellbeing, highlighting the importance of exploring the 'whole package'.

Many participants expressed how the low carbon features were a motivation for moving to an Active Home, enabling them to live well while also taking steps to address climate change. In this way Active Homes and the way of life they were expected to enable connected to participants' personal beliefs and identities (Winther *et al.*, 2018). In several instances, the material configuration of their Active Home contradicted these expectations affecting participants health and wellbeing. For some, moving into an Active Home was expected to enable further low carbon or sustainable daily routines associated with energy prosumption, but due to lack of information, there was confusion as to how to do this most effectively. Relatedly, some participants also expressed uncertainty around the operation of heating systems. Research has shown that household engagement with energy technologies through, for example, prosumption can provide a sense of satisfaction (Ellsworth-Krebs & Reid, 2016; Winther *et al.*, 2018). However, our findings elucidate how inability to effectively operate heating systems or to engage in prosumption can impact sense of identity, control and autonomy (Creaney *et al.*, 2021). Furthermore, while low energy costs experienced by a number of participants were connected with feelings of reassurance and security (Mitchell *et al.*, 2022; Willand *et al.*, 2015), higher than anticipated costs had the opposite impact. At case sites 1 and 3, concern about high energy costs led some participants to compromise their comfort, wellbeing and health through energy rationing. Indeed, for some, the ontological security of their home was questioned (Rolf *et al.*, 2020).

Other material aspects of the home were also raised as working against expectations of an Active Home, holding similar outcomes for participants' health and wellbeing. At case site 2, high technology levels, along with non-completion of public green spaces, was felt by some to contradict the garden village framing of the home design. At case site 3, framed as low carbon and low energy cost, some perceived that air ventilation technology worked against heating systems, wasting energy and increasing energy costs. At case site 1 synthetic, unsustainable materials used in the finish of the homes caused concern for some around VOC release. This finding supports research by van der Grijp *et al.* (2019) where residents commented on contradictions in their low energy home designs, suggesting developers chose minimal rather than optimal solutions. Whilst participants recognized cost constraints as a relevant concern for developers in choosing materials, finishes and technologies, they suggested that greater choice for residents, reflected in different pricing options, could potentially avoid the waste inherent in replacing items post-occupancy, which was counter to expectations of Active Homes.

Finally, lack of clarity about monitoring arrangements meant some participants experienced this as an infringement of household privacy (Fabi *et al.*, 2017) causing

unease and concern, and impacting a sense of home as a private place (Creaney *et al.*, 2021). Interestingly at case site 1 less concern over monitoring or external control was expressed by participants despite the developer having remote control over the homes' energy systems in addition to data monitoring. Instead, many participants here perceived benefits and reassurance around fault identification, that the organizations involved were trustworthy and further, that feelings of pressure and stress in managing their energy systems to be low carbon were alleviated. However, even when residents were unconcerned with data monitoring and expressed having positive relationships with their housing services providers, some remained frustrated that they were unable to access the same level of data or exert the same level of control over their energy system as those monitoring their data (Hansen & Hauge, 2017). This finding has implications for developer assumptions that external monitoring and control is preferable and alleviates residents of the burden of energy management, as for most it appears conditional upon the building of trust and access to accurate information and assistance post-occupancy.

Conclusion

Our research has addressed an identified need for understanding the experiences of low carbon home residents (Berry *et al.*, 2014), showing how Active Homes can hold positive outcomes for residents' health and wellbeing. Participants have described how the production and storage of energy in affordable, efficient, and well-designed homes can alleviate feelings of pressure and stress. Conversely, Active Homes may also highlight new and unintended health risks (WHO, 2011), which centre around new and novel digital-technological configurations within the homes. Our research advances knowledge around health risks associated with climate change mitigation in housing, which has previously identified issues of equality in accessing reduced energy costs and security of supply associated with prosumption, or air-quality risks associated with increased thermal insulation and air-tight building envelopes (WHO, 2011). In particular, questions around the health impacts of various technologies and materials, alongside residents' sense of control, highlight the importance of considering not only which low carbon interventions are installed, but how they interplay with other material and psycho-social aspects of home and what formal and informal governance systems develop around their operation, management and maintenance. It also highlights the importance of fully understanding and making explicit how such interventions may need to be supported by greater levels of information technology than in conventional homes. Our research demonstrates residents' desire to know more about how their homes work, and a willingness to work with the homes to achieve optimum performances. This holds relevance to industry, in particular, low carbon housing designers, architects, developers, and those involved with maintaining technologies and providing landlord management to homes. All stakeholders must be clear on their own and residents' roles in managing energy (demand, production and consumption) and in operating domestic energy technologies; and the energy or other related data required for monitoring or managing energy services. This information should be shared with prospective residents prior to making decisions on whether to move into an Active Home.

Whilst some participants spoke directly of impacts to their physical and mental health, others referred to improved mood, sense of calm, peace, relaxation, happiness, or, conversely, feelings of stress or pressure. This highlights the importance of a detailed view of resident experiences, which can elucidate how these sensed aspects contribute to resident satisfaction, wellbeing and quality of life. We find that a sense of at homeness, and indeed, household health and wellbeing are not gained from single elements of a home. Instead, they are made through interconnections between residents, the values, and expectations of home life they hold, and how this is realized through everyday experiences in the material environment of home. By looking at this 'whole package' of experience we can see how these multiple aspects are crucial to understanding how a healthy and well life may be lived in an Active Home. We also highlight how new iterations of Active Homes must take into consideration not only how the materiality of a home environment may impact residents' health and wellbeing, but how residents are able to emotionally connect with the home and create a sense of at-homeness. This means the material environment, including new and novel technologies, and modes of management and operation, should not infringe on the intrinsic 'less tangible' values expected from home-life or non-negotiable psycho-social routines and norms. This includes enabling positive sensorial experiences such as, being at ease and feeling emotional and physiological warmth (Mitchell *et al.*, 2022); the realization of expected values and ontological security associated with household security, control and autonomy (Rolf *et al.*, 2020; Wågø *et al.*, 2016; Willand *et al.*, 2015); and the formation of positive relationships (Despres, 1991) with others, nature, activities, and place (Öhlén *et al.*, 2014).

Acknowledgements

We thank Dr Rachel Hale who assisted with some data collection and organization. We also thank all the LWLCH participants, without whom the research would not have been possible. We are also grateful for additional part-funding from the Welsh Government through the European Regional Development fund as part of the FLEXIS: Smart Energy for our Future project.

Disclosure statement

The authors report there are no competing interests to declare.

Funding

This work was supported by the Engineering and Physical Sciences Research Council under Grant [EP/S016627/1].

Notes on contributors

Kate O'Sullivan is a Research Associate based in the School of Social Sciences, Cardiff University. Kate's background is in human geography and research interests centre around the relational and multi-scale interplay between humans and environment, and the implications for how places are understood and experienced. Kate's research has included the exploration of decarbonization for peripheral communities in Wales highlighting connections

between spatial structures and the distribution of costs and benefits of decarbonization. Most recently Kate's research has explored the lived experiences of new and novel low and zero carbon homes, including experiences of placemaking processes.

Fiona Shirani is a Research Associate based in the School of Social Sciences, Cardiff University. Since 2011 Fiona has worked on projects concerning energy and sustainability, including the interdisciplinary FLEXIS network and Welsh Government funded Better Energy Futures project. Fiona was part of the Living Well in Low Carbon Homes project, which conducted Social Science research with developers, residents and community members as part of the Active Building Centre Research Programme. She is currently undertaking work on low carbon heating transitions. Fiona's recent published work covers fuel poverty and energy vulnerability as well as low carbon living.

Nick Pidgeon is Professor of Environmental Psychology and Risk at Cardiff University and Director of the Understanding Risk Research Group. His extensive interdisciplinary research portfolio looks at public engagement, communication and decision-making for environmental, energy, and emerging technology risks. He has been a science advisor at the UK Energy and Climate, Environment and Transport Departments. He was awarded an MBE in 2014 for services to UK climate change awareness and energy security policy.

Karen Henwood is a Professor in the School of Social Sciences, Cardiff University. She has research interests in psycho-social risk, values and identities, environmental issues, socio-cultural change, and the low carbon energy transition. She specializes in qualitative social research methodology. Her RCUK and WEFO funded projects have involved carefully designed longitudinal and community case studies and use of interpretive, temporal and multimodal research methods. She has a track record in methodological innovation and development to engage local communities in research.

ORCID

Kate O'Sullivan http://orcid.org/0000-0001-6688-5997
Fiona Shirani http://orcid.org/0000-0002-6963-4971
Nick Pidgeon http://orcid.org/0000-0002-8991-0398
Karen Henwood http://orcid.org/0000-0002-4631-5468

Data availability statement

The data supporting the findings of this study are not publicly available due to containing information that could compromise the privacy of research participants.

References

Berry, S., Whaley, D., Davidson, K. & Saman, W. (2014). Near zero energy homes – what do users think, *Energy Policy*, 73, pp. 127–137.

Committee on Climate Change. [CCC] (2022). Progress in reducing emissions, 2022 Report to Parliament. Available at https://www.theccc.org.uk/publication/2022-progress-report-to-parliament/. (accessed 13 February 2023).

Chiu, L. F., Lowe, R., Raslan, R., Altamirano-Medina, H. & Wingfield, J. (2014). A socio-technical approach to post-occupancy evaluation: interactive adaptability in domestic retrofit, *Building Research & Information*, 42(5), pp. 574–590.

Cozens, P. & Hillier, D. (2008). The shape of things to come: New urbanism, the grid and the cul-De-sac, *International Planning Studies*, 13(1), pp. 51–73.

Creaney, R., Reid, L. & Currie, M. (2021). The contribution of healthcare smart homes to older peoples' wellbeing: A new conceptual framework, *Wellbeing, Space and Society*, 2, pp. 100031. doi: 10.1016/j.wss.2021.100031.

D'Agostino, D. & Mazzarella, L. (2019). What is a nearly zero energy building? Overview, implementation and comparison of definitions, *Journal of Building Engineering*, 21, pp. 200–212.
Despres, C. (1991). The meaning of home: Literature review and directions for future research and theoretical development, *Journal of Architectural and Planning Research*, 8(2), pp. 96–115. https://www.jstor.org/stable/43029026
Ellsworth-Krebs, K. & Reid, L. (2016). Conceptualising energy prosumption: Exploring energy production, consumption and microgeneration in Scotland, UK, *Environment and Planning A: Economy and Space*, 48(10), pp. 1988–2005.
Ellsworth-Krebs, K., Reid, L. & Hunter, C. J. (2015). Home-ing in on domestic energy research: "House," "home," and the importance of ontology, *Energy Research & Social Science*, 6, pp. 100–108.
Ellsworth-Krebs, K., Reid, L. & Hunter, C. J. (2019). Integrated framework of home comfort: Relaxation, companionship and control, *Building Research & Information*, 47(2), pp. 202–218.
Fabi, V., Spigliantini, G. & Corgnati, S. P. (2017). Insights on smart home concept and occupants' interaction with building controls, *Energy Procedia*, 111, pp. 759–769.
Fell, M. J. (2021). The history of heat-as-a-service for promoting domestic demand-side flexibility: Lessons from the case of budget warmth, *Journal of Energy History*, 5, pp. 230. energyhistoryeu/en/node
Gibson, M., Thomson, H., Kearns, A. & Petticrew, M. (2011). Understanding the psychosocial impacts of housing type: Qualitative evidence from a housing and regeneration intervention, *Housing Studies*, 26(04), pp. 555–573.
Hansen, M. & Hauge, B. (2017). Scripting, control, and privacy in domestic smart grid technologies: Insights from a Danish pilot study, *Energy Research & Social Science*, 25, pp. 112–123.
Lovell, R. (2018). (ed.) Demystifying health, valuing nature paper VNP13. Available at https://valuing-nature.net/demystifying-health (accessed 14 November 2023).
Lowther, S. D., Jones, K. C., Wang, X., Whyatt, D. J., Wild, O. & Booker, D. (2019). Particulate matter measurement indoors: a review of metrics, sensors, needs, and applications, *Environmental Science & Technology*, 53(20), pp. 11644–11656.
Madsen, L. V. (2018). Materialities shape practices and notions of comfort in everyday life, *Building Research & Information*, 46(1), pp. 71–82.
Madsen, L. V., Hansen, A. R. & Larsen, S. P. A. K. (2023). Embodied competencies and smart home technology in energy use: Three ways users integrate smart heating systems in everyday practices, *Energy Efficiency*, 16(6), pp. 16–55.
Mel, I. & Whitten, M. (2021). Access to nature in a post covid-19World: Opportunities for green infrastructure financing, distribution and equitability in urban planning, *International Journal of Environmental Research and Public Health*, 18(4), pp. 1527.
Mitchell, T. K., Bray, L., Blake, L., Dickinson, A. & Carter, B. (2022). 'It doesn't feel like our house anymore': the impact of medical technology upon life at home for families with a medically complex, technology-dependent child, *Health & Place*, 74, pp. 102768.
Murphy, M. (2006). *Sick building syndrome and the problem of uncertainty* (London: Duke University Press).
Ohlén, J., Ekman, I., Zingmark, K., Bolmsjö, I. & Benzein, E. (2014). Conceptual development of "at-homeness" despite illness and disease: A review, *International Journal of Qualitative Studies on Health and Well-Being*, 9(1), pp. 23677.
O'Sullivan, K., Henwood, K. & Pidgeon, N. (2020). Active buildings in the changing policy landscape: Conceptual challenges and social scientific perspectives. Available at https://abc-rp.com/impact/white-papers/ (accessed 16 February 2023).
O'Sullivan, K., Shirani, F., Pidgeon, N. & Henwood, K. (2022). Why active buildings? Realising the potentials of energy networked homes: A social scientific perspective, in: V. Vahidinasab & B. Mohammadi-Ivatloo (Eds) *Active Building Energy Systems. Operation and Control*, pp. 25–49 (Cham: Springer).
Palm, J., Eidenskog, M. & Luthander, R. (2018). Sufficiency, change, and flexibility: Critically examining the energy consumption profiles of solar PV prosumers in Sweden, *Energy Research & Social Science*, 39, pp. 12–18. doi: 10.1016/j.erss.2017.10.006.

Rice, L. (2019). A health map for architecture: The determinants of health and wellbeing in buildings, in: M. Jones, L. Rice, F. Meraz and G. Cairns (Eds) *Designing for Health and Wellbeing*. Home, City, Society, pp. 155–184 (Malaga: Vernon Press).
Rolf, S., Garnham, L., Godwin, J., Anderson, I., Seaman, P. & Donaldson, C. (2020). Housing as a social determinant of health and wellbeing: Developing an empirically informed realist theoretical framework, *BMC Public Health*, 20(1), pp. 1138.
Seamon, D. (1979). *A Geography of the Lifeworld: Movement, Rest and Encounter* (London: Croom Helm Ltd).
Sharpe, R. A., Williams, A. J., Simpson, B., Finnegan, G. & Jones, T. (2022). A pilot study on the impact of a first-time Central heating intervention on resident mental wellbeing, *Indoor and Built Environment*, 31(1), pp. 31–44.
Shirani, F., Groves, C., Henwood, K., Pidgeon, N. & Roberts, E. (2020). 'I'm the smart meter': Perceptions and experiences of smart technology amongst vulnerable consumers, *Energy Policy*, 144, pp. 111637.
Shirani, F., O'Sullivan, K., Hale, R., Pidgeon, N. & Henwood, K. (2022a) Transformational innovation in home energy: How developers imagine and engage with future residents of low carbon homes in the United Kingdom, *Energy Research & Social Science*, 91, pp. 102743.
Shirani, F., O'Sullivan, K., Henwood, K., Hale, R. & Pidgeon, N. (2022b) Living in an active home: Household dynamics and unintended consequences, *Buildings and Cities*, 3(1), pp. 589–604.
Shirani, F., O'Sullivan, K., Hale, R., Pidgeon, N. & Henwood, K. (2022c) From active houses to active homes: Understanding resident experiences of transformational design and social innovation, *Energies*, 15(19), pp. 7441.
Stikvoort, B., Bartusch, C. & Juslin, P. (2020). Different strokes for different folks? Comparing pro-environmental intentions between electricity consumers and solar prosumers in Sweden, *Energy Research & Social Science*, 69, pp. 1–12. doi: 10.1016/j.erss.2020.101552.
van der Grijp, N., van der Woerd, F., Gaiddon, B., Hummelshøj, R., Larsson, M., Osunmuyiwa, O. & Rooth, R. (2019). Demonstration projects of nearly zero energy buildings: Lessons from end-user experiences in Amsterdam, Helsingborg, and Lyon, *Energy Research & Social Science*, 49, pp. 10–15.
Wang, D. & Wang, F. (2016). Contributions of the usage and affective experience of the residential environment to residential satisfaction, *Housing Studies*, 31(1), pp. 42–60.
Wågø, S., Hauge, B. & Støa, E. (2016). Between indoor and outdoor: Norwegian perceptions of well-being in energy-efficient housing, *Journal of Architectural and Planning Research*, 33(4), pp. 326–346.
Welsh Government. (2020). Innovative housing programme. Available at https://gov.wales/innovative-housing-programme (accessed 15 May 2022).
World Health Organisation [WHO]. (1995). Constitution of the World Health Organization. *World Health Organization: Basic documents*, 45th ed. (Geneva:).
World Health Organisation [WHO]. (2011). Health in the green economy. *Health co-benefits of climate change mitigation – Housing sector*. Available at https://apps.who.int/iris/handle/10665/44609 (accessed 13 February 2023).
World Health Organisation [WHO]. (2018). WHO housing and health guidelines. Available at https://www.who.int/publications/i/item/9789241550376 (accessed 13 February 2023).
Willand, N., Maller, C. & Ridley, I. (2019). Addressing health and equity in residential low carbon transitions – insights from a pragmatic retrofit evaluation in Australia, *Energy Research & Social Science*, 53, pp. 68–84.
Willand, N., Ridley, I. & Maller, C. (2015). Towards explaining the health impacts of residential energy efficiency interventions, a realist review. Part 1: Pathways, *Social Science & Medicine (1982)*, 133, pp. 191–201.
Winther, T., Westskog, H. & Sæle, H. (2018). Like having an electric car on the roof: Domesticating PV solar panels in Norway, *Energy for Sustainable Development*, 47, pp. 84–93.
Xue, F., Gou, Z., Siu-Yu Lau, S., Lau, S., Chung, K. & Zhang, J. (2019). From biophilic design to biophilic urbanism: Stakeholders' perspectives, *Journal of Cleaner Production*, 211, pp. 1444–1452.